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Abstract

Virtual reality (VR) distraction has become increasingly available in health care contexts and is used in acute pain management. However, there has been no systematic exploration of the importance of the *content* of VR environments. Two studies tested how interacting with nature VR influenced experienced and recollected pain after 1 week. Study 1 ($n = 85$) used a laboratory pain task (cold pressor), whereas Study 2 ($n = 70$) was a randomized controlled trial with patients undergoing dental treatment. In Study 1, nature (coastal) VR reduced both experienced and recollected pain compared with no VR. In Study 2, nature (coastal) VR reduced experienced and recalled pain in dental patients, compared with urban VR and standard care. Together, these data show that nature can improve experience of health care procedures through the use of VR, and that the content of the VR matters: Coastal nature is better than urban.

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pain, virtual reality, nature benefits, coastal environment, patient experience

Not only are many medical procedures painful and anxiety provoking in patients (Sinatra, 2010), but these aversive experiences can undermine patients' willingness to undergo or continue treatment (Redelmeier, Katz, & Kahneman, 2003). This phenomenon is of particular relevance in the context of dentistry. Some people avoid or delay dental care because they experience fear and anxiety (Chlan, Evans, Greenleaf, & Walker, 2000), and the expectation of pain has been identified as a major barrier to seeking dental care (Doerr, Lang, Nyquist, & Ronis, 1998). Despite advances in dental care, patients still rate dental treatment as painful (Tickle, Milsom, Crawford, & Aggarwal, 2012; Vassend, 1993), and dental anxiety is often related to the experience of pain (McNeil et al., 2011). It has been suggested that reducing the experience of pain and anxiety would lead to less unpleasant memories of the experience, and as a consequence increase the likelihood of future oral health care attendance (Tanja-Dijkstra et al., 2014a; Wilson, McNeil, Kyle, Weaver, & Graves, 2014).

A variety of distraction interventions, such as watching television, listening to music, and more recently the use of virtual reality (VR), are not only used in daily practice to help patients cope with unpleasant procedures in dentistry but also in other health care contexts (Hudson, Ogden, & Whiteley, 2015; Mahrer & Gold, 2009). Distraction is thought to help patients cope with pain and other aversive experiences, and is often combined with relaxation or pleasant imagery (McCaul, Monson, & Maki, 1992). Due to recent technical advances, VR distraction has become increasingly available and is used in acute pain management (Garrett et al., 2014; Hoffman et al., 2006; Rutter, Dahlquist, & Weiss, 2009). Using VR has been shown to reduce pain during burn treatment (Guo, Deng, & Yang, 2015; Kipping, Rodger, Miller, & Kimble, 2012; Schmitt et al., 2011). More recently, in the context of dental care, one study demonstrated that distracting children with 3D video glasses during administration of local analgesia resulted in a reduction of anxiety (Nuvvula, Alahari, Kamatham, & Challa, 2015). In a simulated dental situation, VR distraction influenced the vividness of memories 1 week later for participants with higher levels of dental anxiety (Tanja-Dijkstra et al., 2014a). Despite these insights into the potential effectiveness of VR distraction in health care situations, to date there has been no systematic exploration of the importance of the *content* of VR environments on outcomes.

Some studies on the effectiveness of VR distraction as an analgesic have used natural environments, such as forests (Mühlberger, Wieser, Kennntner-Mabiala,

Pauli, & Wiederhold, 2007), snowy canyons (Hoffman et al., 2004; Schmitt et al., 2011), or (in a dental context) a botanical garden (Furman et al., 2009). This choice of natural environments did not appear to be theoretically motivated even though there is a substantial body of work surrounding the health and well-being benefits of nature exposure more generally (Hartig, Mitchell, De Vries, & Frumkin, 2014).

Previous research demonstrated that natural environments can reduce feelings of stress and anxiety and improve mood compared with urban environments (Hartig et al., 2014; McMahan & Estes, 2015), and coastal environments appear particularly beneficial (White, Alcock, Wheeler, & Depledge, 2013). Most evidence relates to direct interactions with nature, but in practice access may be restricted, especially in potentially painful or anxiety-inducing health care contexts. A small but growing body of work has examined the possibility of introducing natural elements in health care settings, to reduce pain, stress, and anxiety. In a pioneering study, Ulrich (1984) was the first to provide evidence on the effects of a window view on trees (vs. brick wall) on the intake of pain medication and length of stay. More recent studies demonstrated small stress-reducing effects of the use of indoor plants in a waiting room (Beukeboom, Langeveld, & Tanja-Dijkstra, 2012), and effects of distraction with nature images and sounds on pain control during a medical procedure (Diette, Lechtzin, Haponik, Devrotes, & Rubin, 2003). While these studies tend to demonstrate small effect sizes, they offer indications of the potential benefits of nature-based interventions in health care. Combining nature stimuli with advances in VR technology avoids issues around real plants in health care settings (hygiene, care) and has not been studied systematically.

The present work integrates research exploring the analgesic properties of VR use and the use of nature interventions in health care contexts. Moreover, we examined recollections of pain a week later, in addition to experienced pain. Expectations of future experiences are heavily influenced by recollections (however accurate), rather than the actual original experiences (Kent, 1985), and these recollections influence people's willingness to return for further treatment (Redelmeier et al., 2003). Thus, designing an intervention that is able to reduce recollections of pain may be just as important as one that improves people's current experiences.

Within the experience and memory of potentially painful treatment, mental images may be particularly important because they can motivate and trigger behavior. This image-behavior link has recently been discussed in different contexts using elaborated intrusion (EI) theory (Kavanagh, Andrade, & May, 2005). This theory originally described how images can motivate consumption behavior for food, drugs, and other

pleasurable substances. It postulates the cognitive processes by which images translate into actions: First, pleasurable initial thoughts (about a desired food, for example) intrude into a person's current activities. These are then elaborated using vivid sensory imagery, especially visual imagery and thus gain strength. The resulting positive associations and emotions then motivate consumption of unhealthy substances despite healthy intentions. Boomsma, Pahl, and Andrade (2016) recently outlined the motivational role of mental images in proenvironmental behavior, describing how such images have the potential to translate abstract values into positive action through the same elaboration process. Despite very different contexts, this theoretical approach emphasizes the crucial role of mental imagery in determining behavioral outcomes. This opens up an intriguing link to using VR technology. If VR could be used to disrupt the formation of negative mental images, this should lead to better treatment experiences and possibly even less remembered pain. Thus, the process could be highly relevant in the context of potentially painful health care treatments because elaborating threatening images is likely to undermine future attendance and contribute to negative health outcomes.

We already know that heightened emotion and arousal during an event increase the likelihood of recollections of the event being triggered by situational cues (Brewin, Dalgleish, & Joseph, 1996). For example, the smell of antiseptic might trigger aversive imagery of dental treatment. This cycle of intrusive recall and distressing imagery can be blocked by performing visuospatial tasks during exposure to aversive video material (Holmes & Bourne, 2008; Stuart, Holmes, & Brewin, 2006), so we predicted that exposure to virtual nature during painful or anxiety-provoking procedures would have a similar effect, reducing encoding of sensory information and thereby making the memory of the experience less vivid, less emotive, and less likely to be elaborated and influence decisions about future treatment.

We investigated these predictions in both a laboratory setting (Study 1) and in a real dental context, including treatments such as tooth extractions and fillings (Study 2, a randomized controlled trial). Our central hypothesis was that interacting with a VR coastal environment would reduce experienced pain in the present, and lead to less recollected pain, and less vivid and intrusive recollections a week later. In Study 2, we added an explicit test of VR content. Here, we hypothesized that interacting with the VR coast would result in more positive outcomes than interacting with an urban VR setting. Support for this second hypothesis would suggest that any benefits are not merely due to the distraction potential of VR but also due to a function of the type of environment one encounters.

Study I

Before undertaking a randomized controlled trial in a real health care context, we tested our VR approach in a controlled laboratory context. With VR technology, an advanced human–computer interface allows people to interact with and become immersed in a computer-generated environment (Riva & Gaggioli, 2008). This virtual environment provides visual information and can be manipulated actively with a controller such as a joystick (Dahlquist, Herbert, Weiss, & Jimeno, 2010). Discussions on the effectiveness of VR distraction have included the technical properties of the technical equipment being used (e.g., Hoffman et al., 2004) and the level of interactivity of the virtual environment (Dahlquist et al., 2007). There are some indications (Dahlquist et al., 2007) that being able to manipulate the virtual environment with a joystick (active use of the VR environment) is more beneficial than passively watching a virtual environment (passive use of the VR environment). However, many studies using 3D video glasses, thereby offering a situation of passive VR use, still demonstrate effects on anxiety (Nuvvula et al., 2015) or pain (Aminabadi, Erfanparast, Sohrabi, Oskouei, & Naghili, 2012). We therefore choose to include both an active VR and a passive VR group in this study.

Method

We used the cold pressor task to create a painful experience (Von Baeyer, Piira, Chambers, Trapanotto, & Zeltzer, 2005) and included three conditions: (a) The simulated “standard care” involved participants wearing VR goggles that were switched off. There were two “treatment” conditions. (b) In the “active” VR condition, participants could explore the VR coastal environment themselves using a handset controller. (c) In the “passive” VR condition, participants watched a replay of a walk through the coastal environment. They were exposed to the same environment but had no control over the walk. We hypothesized that exposure to both the active/passive VR coast would be associated with lower experienced pain and recollected pain a week later than would standard care; both VR coast conditions would be associated with fewer negative intrusive thoughts and vivid negative images a week later.

Participants. A total of 85 participants (51 female; age $M = 21.72$, $SD = 4.67$) were recruited from a student participant pool and received course credits or £4 for their participation. A formal sample size calculation was not performed due to the novel character of the study, but the sample size was informed by



Figure 1. The virtual coastal environment.

previous cold pressor studies, which tend to include between 20 and 25 participants per experimental condition (e.g., Dahlquist et al., 2010; Sil et al., 2014). One participant was subsequently excluded from the analyses reported due to a research protocol violation (i.e., cold water temperature of 7.5 °C); including this participant does not change the pattern of results.

Materials. The VR environment consists of a coastal path, complete with sea views, a beach and field areas (see Figure 1; Depledge, Stone, & Bird, 2011). The VR environment was constructed using commercially sourced topographical geometry and aerial photographic images, and the resulting 3D model was used as a template to enable the virtual environment to be populated with additional 3D assets and photographic textures, including the accurate representations of the few buildings at the site, trees, plants, and other features.

A Vuzix iWear VR920 headset was connected to an Alienware M11X laptop (dual core, 1.3 GHz Intel processor with Nvidia GT 540M graphics card) and used to display the virtual environment. Participants in the active condition were able to explore the virtual environment from a first-person perspective, by using a Zeemote JS1 Thumbstick Controller.

For the cold pressor task, we used a plastic tub with a pump to circulate the water and to ensure that the water would not warm up around the hand (Mitchell, MacDonald, & Brodie, 2004; see Figure 2 for the setup). The temperature of the water was maintained at 7.0 °C (6.8-7.2°C was accepted).



Figure 2. The setup of the study.

This moderate temperature was chosen, so that we could ensure a reasonable time of VR exposure during the pain experience. Participants used their dominant hand to hold the controller (in the active VR group) and their nondominant hand for the cold pressor task.

Procedure and measures. The study was approved by the ethics review board of the authors' institution. Following consent procedures, participants were assigned to one of three conditions in a randomized between-participants design: (a) active VR, (b) passive VR, (c) standard care (no VR). While a baseline task is sometimes included in the standard cold pressor paradigm to control for individual differences, we felt that this could be confusing to our participants when answering our recall questions. Thus, we omitted the baseline cold pressor task.

Participants first received instructions for the cold pressor task and the VR equipment. They were asked to abstain from analgesics (48 hr before), alcohol (12 hr), caffeine (2 hr), and nicotine (1 hr) use prior to participation. Participants were excluded from participation if they had any condition that would be exacerbated by or stop them from putting their hand in very cold water (e.g., poor circulation, arthritis, Raynaud's disease). Due to the size of the VR headset, participants wearing glasses were also excluded.

To provide a common baseline, participants placed their nondominant hand in a warm water tank (37 °C) for 2 min at the start of the study (Von Baeyer et al., 2005). The VR was started and after 30 s, the experimenter placed the hand of the participant in the cold water (6.8-7.2 °C). Participants were instructed to remove their hand when the pain became unbearable, and they were unaware that an upper limit of 4 min was set for safety reasons. The number of seconds participants kept their hand in the water was recorded. After completing the cold pressor task, participants completed a computerized questionnaire measuring the pain experience and stress. A follow-up phone call was scheduled 1 week after the lab session; participants were thus aware of the follow-up assessment but were not informed of the topics the follow-up interview would address. During this phone interview, participants were asked to rate recalled pain, vividness of their memories, and intrusive thoughts.

Pain experience was measured with an 11-point numeric rating scale (NRS), ranging from *no pain at all* (0) to *pain as bad as it could be* (10). Additionally, the short form of the McGill Pain Questionnaire (SF-MPQ; Melzack, 1987) was used, which ranges from *none* (0) to *severe* (3); the average score on the 15 items was calculated ($\alpha = .80$). The NRS is used in both research and clinical practice, and the SF-MPQ is a validated measure to assess pain (Breivik et al., 2008). The two measures were positively correlated, $r = .54$.

At 1-week follow-up, remembered pain was assessed with the same 11-point NRS used immediately after the cold pressor task. We developed a questionnaire in an 11-point NRS format that assessed intrusive thoughts of the experience ($\alpha = .71$, three items) and vividness of memories of the experience ($\alpha = .83$, four items). Mean scores were calculated for both constructs. Intrusive thoughts were measured with the following items: (a) How often have you thought about the visit to the lab in the past week? (b) To what extent did your thoughts about the visit pop into your mind spontaneously? (c) How hard were you trying not to think about the visit in the past week? Vividness of memories was measured with the following items: (a) How vividly do you picture the visit? (b) How vividly do you feel the emotions you experienced? (c) How vividly do you remember the discomfort of holding your hand in the cold water? (d) How vividly do you remember the pain you experienced during the cold water task? (adapted from the Alcohol Craving Experience questionnaire, Statham et al., 2011).

Analysis strategy. The hypotheses were tested using a series of ordinary-least-squares (OLS) regressions where the psychological variables (e.g., pain, vividness) were the dependent variables, condition information was entered in

Table 1. Means and Standard Deviations for Key Variables in Study 1.

	Active VR (<i>n</i> = 29)	Passive VR (<i>n</i> = 28)	Control (<i>n</i> = 28)
Measures	<i>M</i> (<i>SD</i>)	<i>M</i> (<i>SD</i>)	<i>M</i> (<i>SD</i>)
Experienced pain	6.59 (2.15)	6.79 (2.33)	7.68 (1.72)
SF-MPQ (pain)	1.84 (0.46)	1.91 (0.44)	2.13 (0.46)
Recalled pain	5.03 (1.92)	5.32 (2.20)	6.54 (1.32)
Vividness memories	5.90 (1.50)	5.78 (2.21)	6.34 (1.34)
Intrusive thoughts	1.93 (1.41)	1.87 (1.33)	2.06 (1.48)

Note. Scores on experienced pain, recalled pain, vividness memories, and intrusive thoughts ranged from 0 to 10; scores on SF-MPQ ranged from 0 to 3. SF-MPQ = short form of the McGill Pain Questionnaire; VR = virtual reality.

Block 1 to test the hypotheses, and age and gender variables were entered in Block 2. We used dummy coding for the condition variable to test the specific research questions. To test the effect of VR versus no VR, we coded the no VR conditions 0 and both active and passive VR 1. Next, to test if active engagement with VR was important, passive VR was coded 0 and active VR was coded 1.

Results

Pain. Across conditions, participants did not significantly differ in the length of time they kept their hands in the water: active VR ($M = 165.66$ s, $SD = 83.59$); passive VR ($M = 165.00$ s, $SD = 94.72$); controls ($M = 134.41$ s, $SD = 95.15$), $F(2, 85) = 1.08$, $p = .344$, see Table 1 for the means and standard deviations for the key variables in Study 1.

Participants in the VR conditions reported less experienced pain (single item) immediately after the cold pressor task than did control (see Table 2). Accounting for age and gender puts this effect below the threshold of statistical significance, although the effect size remained similar. There was no main effect of age, but females reported more pain than did males. In short, exposure to the coastal VR reduced experienced pain by approximately 1 point on the 11-point scale. Similar results were obtained with the SF-MPQ, with exposure to VR reducing reported pain immediately after the cold pressor task, $B = -.25$ ($SE = 0.10$), $\beta = -.25$, $p = .019$. This effect remained significant after adding age and gender, $B = -.24$ ($SE = 0.10$), $\beta = -.24$, $p = .024$.

VR reduced the intensity of recalled pain (single-item NRS) at 1 week follow-up. Gender, but not age, was again significant, but the main effect of condition remained significant once these variables were added. The variance

Table 2. Summary of Regression Analyses for Experienced Pain (Single Item) and Recalled Pain (Single Item) in Study 1.

Variable	Experienced pain						Recalled pain					
	Model 1			Model 2			Model 1			Model 2		
	B	SE	B	SE	B	SE	B	SE	B	SE	B	SE
VR	-.99	0.48	-.22*		-.93	0.47	-.21		-1.36	0.43	-.33**	
Age					.63	0.05	.14				.07	
Gender					.93	0.46	.22*				.86	
R ²				.05						.11		.18
F for change in R ²				4.32*						10.26**		3.27*
Model F				4.32*						10.26**		5.78**

Note. Scores on experienced and recalled pain ranged from 0 to 10. VR = virtual reality.

* $p < .05$. ** $p < .01$.

explained by our models was greater for recalled pain than for experienced pain ($R^2 = .18$).

Vivid memories and intrusive thoughts. There was, however, no support for the hypothesis that the VR experience would lead to less vivid memories than the control experience ($B = -.50$ [$SE = 0.40$], $\beta = -.14$, $p = .208$), or fewer intrusive thoughts during the week ($B = -.16$ [$SE = 0.32$], $\beta = -.05$, $p = .624$); results were unaffected by controlling for age and gender.

Active versus passive use of VR. Furthermore, there was no support for the hypothesis that active VR, compared with passive VR, would be associated with significantly less experienced pain ($B = .22$ [$SE = 0.58$], $\beta = .05$, $p = .709$) and recalled pain ($B = .22$ [$SE = 0.54$], $\beta = .06$, $p = .684$); results were not affected by controlling for age and gender.

Discussion

Supporting our primary hypotheses, using the coast VR resulted in lower pain immediately after the cold pressor task and at recall a week later, compared with “standard care.” However, we found no evidence for effects on vividness and intrusive thoughts predicted by EI theory. The mean scores on intrusive thoughts in particular were very low (see Table 1). This lack of findings is most likely due to the characteristics of the cold pressor task, being a non-threatening and artificial situation that offers optimal situational control to the participant. So despite it being a very useful paradigm to study effects of pain, it appears to be less useful for testing predictions based on EI theory. We also found no evidence that active VR was better than passive VR, contrary to previous findings that showed that interactivity improved pain tolerance (Dahlquist et al., 2007).

Nevertheless, we felt that the support for our main hypotheses about pain was sufficient to take the study out of the lab and into the field, specifically into the context of patients experiencing dental treatment. Some changes were made to the design. In particular, rather than having a passive VR condition, we substituted this for an alternative active urban VR environment. An urban environment was chosen as in theory this should be equally as distracting but less psychologically “restorative” than a natural environment such as the coast (Hartig, Böök, Garvill, Olsson, & Gärling, 1996; Hartig et al., 2014). Individuals vary in dental anxiety (which is related to treatment outcomes), so a measure of this was also included. We only included the one-item measure of pain not the SF-MPQ, because time was severely restricted in this field study.

Study 2

Rationale for Study 2

Study 2 investigated similar outcomes of experienced and recollected pain but in the health care context of dental treatment. This time, real patients volunteered to take part in the research, and either received standard care or engaged with either the coastal VR or an urban VR setting during their treatment. Note that during routine dental treatment, additional pain management is provided through provision of local anesthetics. As in Study 1, we hypothesized that experienced and recollected pain would be lower in the VR coast than standard care condition. In addition, given prior evidence of the importance of nature (Hartig et al., 2014), we predicted that experienced and recalled pain would be lower in the VR coast than in the urban VR condition. This mechanism would be further supported if we found that the coast VR was perceived as more restorative than the urban VR. Finally, we again tested the two mechanisms underpinning any differences in recalled pain as proposed by EI theory, and predicted that the coast VR would be associated with the fewest negative intrusive thoughts and images of the three conditions. Despite failure to support these findings in Study 1, we reasoned that given that the theory and measures were developed in applied health psychology contexts, they might be more applicable and sensitive in the current field trial.

The study was approved by a medical ethics committee in the United Kingdom. A complete description of the study protocol is published elsewhere (Tanja-Dijkstra et al., 2014b).

Method

Participants. Of the 87 patients who consented to participate, two withdrew their consent and five did not return for treatment. Of the 80 randomized patients, five participants were unable to continue in the VR condition due to technical issues, and another four patients requested to stop the VR, one patient had to be excluded, as that individual was below 18 years of age. A total of 70 patients were thus included in the analysis, with 11 of these dropping out at 1-week follow-up (see Online Appendix for flow chart and Table 3 for baseline characteristics of the participants). Preliminary statistical checks confirmed that the three groups did not differ on any of the characteristics listed in Table 3 (all $F < 1$, all $\chi^2 p > .33$). Details about the dental treatment were recorded by the dentist.

Data from our own pilot work in a simulated dental setting (Tanja-Dijkstra et al., 2014a) were used in the sample size calculation. This calculation (with a power of 0.80, significance level of .05 and based on two-sided testing) is based

Table 3. Summary of Baseline Characteristics in Study 2.

	Standard care (n = 28)	Urban VR (n = 22)	Coast VR (n = 20)
Measures	M (SD)/n (%)	M (SD)/n (%)	M (SD)/n (%)
Baseline dental anxiety	13.16 (5.67)	12.57 (6.11)	13.42 (5.50)
Length of treatment (min)	13.46 (4.86)	13.18 (4.63)	13.15 (6.33)
Age	45.04 (15.05)	44.36 (14.49)	46.0 (16.78)
Gender			
Female	17 (60.7%)	12 (54.5%)	11 (55%)
Male	11 (39.3%)	10 (45.5%)	9 (45%)
Type of treatment			
Filling	23 (82.2%)	20 (91%)	15 (75%)
Extraction	2 (7.1%)	1 (4.5%)	4 (20%)
Both	3 (10.7%)	1 (4.5%)	1 (5%)
Sedation			
No sedation	24 (85.7%)	20 (91%)	19 (95%)
RA	4 (14.3%)	2 (9%)	1 (5%)

Note. VR = virtual reality; RA = relative analgesia.

on one of the main outcomes related to memories, “intrusive thoughts,” as measured with an 11-point NRS. A total sample size of 90 patients (i.e., 30 per group) would allow the detection of a between-group difference of around 0.82 units (i.e., a moderate effect size, see for details, Tanja-Dijkstra et al., 2014b).

Materials. Two VR environments were used in the study: the coast VR from Study 1, extended considerably to provide navigation options for up to 30 min, and an urban environment (Figure 3). The urban environment was developed specifically for this study, taking a conservative approach by including some natural elements (e.g., trees, a fountain) and making this environment look well maintained and pleasant. A Sony personal 3D viewer headset (Figure 4) was connected to an Alienware gaming laptop and used to display the VR environment. The headset consists of two displays with a 1,280 × 720 resolution, provides a 45° field of view, and weighs 330 g. In contrast to the headset used in Study 1, this headset can be fitted over glasses. Patients used a Zeemote JS1 Thumbstick Controller to explore the environments from a first-person perspective.

Procedure and measures. This study included patients 18 years or older who were scheduled to undergo dental treatment for fillings and/or extraction,



Figure 3. The virtual urban environment.



Figure 4. The VR headset used in Study 2.

Note. VR = virtual reality.

with a maximum anticipated appointment duration of 30 min. Both patients who needed relative analgesia (RA), which is a pharmacologically induced form of conscious sedation, and those treated without sedation were included. For both groups, the dentist provided local anesthetics to provide significant management of pain (unlike the laboratory setting in which no supplementary pain control was provided). Patients were randomized into three groups: (a) standard care + coast VR, (b) standard care + urban VR, and (c) standard care control group. Randomization was done prior to the study using a computerized stratified block design. Two strata were used: (a) by sedation (RA: yes or no) and (b) by dentist who performed the treatment (Dentist 1 or Dentist 2). Randomization was concealed via sequentially numbered opaque sealed envelopes, and was revealed by the dentist or nurse who started the VR, immediately prior to commencing treatment. At that point, staff were no longer blinded for condition.

Dental anxiety was measured at baseline, using the Modified Dental Anxiety Scale (MDAS), which consists of five items (Humphris, Morrison, & Lindsay, 1995). A total score was calculated by summing up the scores of the five items, with totals ranging from 5 to 25. The baseline questionnaire was completed on average 4 weeks before treatment. Immediately after treatment, measures regarding the experience of the dental treatment (e.g., experienced pain and stress) and the VR experience (e.g., evaluation of the VR environments) were collected using a paper-based questionnaire. Experienced pain was measured using the same 11-point NRS as used in Study 1; stress was measured using a self-reported measure consisting of five items on a 5-point scale from the tension dimension from the Profile of Mood States, $\alpha = .95$ (McNair, Lorr, & Droppleman, 1971). The questions about the VR experience were only asked to patients in the two VR groups. Presence was measured with six items on 11-point NRSs based on the IGroup Presence Questionnaire (Schubert, Friedmann, & Regenbrecht, 2001) and the Reality Judgment and Presence Questionnaire (Baños et al., 2000; $\alpha = .87$). Research showed that the VR technology used can influence levels of presence and the analgesic effects of VR use (Hoffman et al., 2004), and it is therefore important to ensure a similar level of presence in both VR environments. Attractiveness of the VR environments was measured with five items on a 5-point Bipolar Adjective scale (Lohr & Pearson-Mims, 2000; $\alpha = .69$). Perceived restoration was measured with eight items on a 5-point scale (Hartig, Korpela, Evans, & Gärling, 1997; $\alpha = .80$). Based on the general notion within the literature on restorative environments that natural environments are rated as more attractive and associated with a higher level of perceived restorativeness, we included these measures to underline this basic difference between the two VR environments used in our study.

Patients were contacted after 1 week and completed a telephone-based questionnaire assessing measures related to memories of the experience. Recalled pain was measured with the same 11-point NRS as Study 1. Vividness of memories (five items, $\alpha = .74$) items was adapted from Study 1 to fit the clinical, dental context of this study and measured with the following items: (a) How vividly do you picture the visit? (b) How vividly do you feel the emotions you experienced? (c) How vividly do you remember the discomfort of holding your mouth open? (d) How vividly do you remember the sounds of the dental instruments? (e) How vividly do you remember the smell in the dental practice? The intrusive thoughts measure (three items, $\alpha = .82$) was identical to Study 1.

The study was conducted between August 2013 and October 2014 at a dental practice in the United Kingdom. Two dentists were involved in the study planning, but circumstances meant that one was only able to treat one patient. The other dentist thus treated more patients than initially planned but reached her maximum capacity before we reached the targeted number. We therefore terminated the study at this point, with 87 patients consented.

Analysis strategy. As with Study 1, we used OLS regressions with condition entered in Block 1, adding potential covariates to Block 2. Block 2 variables were more important here because they included uncontrollable differences in treatment across conditions such as type and duration of treatment, as well as trait Dental Anxiety. Treatment type was coded as follows: 0 = filling, 1 = extraction or extraction + filling. There were no significant differences in these variables as a function of condition. To recap, unlike Study 1, where both VR conditions were of the same coastal environment, and people interacted with them differently, Study 2 had two different VR environments, and thus we did not collapse across VR conditions here. Instead, two dummy variables for condition were created: coast = 1, else 0; and urban = 1, else 0. This enabled us to directly compare both conditions simultaneously with standard care as the reference category. In a second step, we tested the direct comparison of the two VR environments to provide further evidence that the content of the VR environment matters.

Results

Pain. Engaging with the coast VR was associated with significantly less experienced pain than standard care (see Table 4). This effect remained significant after controlling for age, gender, dental anxiety, type and duration of treatment. By contrast, there was no difference in experienced pain between the urban VR and standard care, either before or after controls were added.

Table 4. Summary of Regression Analysis for Predicting Experienced Pain and Recalled Pain in Study 2.

Variable	Experienced pain (n = 64)					Recalled pain (n = 54)				
	Model 1		Model 2			Model 1		Model 2		
	B	SE B	β	B	SE B	β	B	SE B	β	B
Coast VR	-2.06	0.66	-.41**	-2.08	0.63	-.41**	-1.65	0.75	-.32*	-1.66
Urban VR	-.59	0.63	-.12	-.41	0.61	-.09	-.39	0.74	-.08	-.37
Age				-.02	0.02	-.13				-.01
Gender				-.50	0.58	-.11				-.40
Dental anxiety				.07	0.05	.17				.01
Treatment type				.99	0.74	.16				.48
Length of treatment				.08	0.05	.19				.10
R ²		.14			.29			.09		.15
F for change R ²		4.98*			2.41*			2.56		0.61
Model F		4.98*			3.31**			2.56		1.14

Note. Scores on experienced and recalled pain ranged from 0 to 10. VR = virtual reality.

*p < .05. **p < .01.

Table 5. Means and Standard Deviations for Key Variables in Study 2.

Measures	Coast VR	Urban VR	Standard care control
	<i>M</i> (<i>SD</i>)	<i>M</i> (<i>SD</i>)	<i>M</i> (<i>SD</i>)
Pain	0.63 (0.90)	2.05 (2.63)	2.63 (2.32)
Stress	0.87 (0.78)	1.18 (1.28)	1.72 (1.22)
Recalled pain	1.28 (1.49)	2.56 (2.28)	2.96 (2.72)

Note. Scores on experienced and recalled pain ranged from 0 to 10, scores on stress ranged from 1 to 5. VR = virtual reality.

None of the control variables were significantly associated with experienced pain in their own right. These effects were maintained 1 week later (Table 3). Specifically, recalled pain was lower in the coast VR than in standard care group, but there was again no difference between the urban VR and standard care; effects remained when controls were added.

The different findings for coast versus urban VR compared with standard care are not an artifact of our statistical approach. Regressions comparing the two VR conditions directly (excluding standard care) found that coast VR participants reported significantly lower experienced pain ($B = -1.41$ [$SE = 0.63$], $\beta = -.34$, $p = .031$). The difference between coast and urban VR for recalled pain was below the conventional threshold for statistical significance but had a similar effect size; it is likely that the suboptimal sample size played a role here ($B = -1.28$ [$SE = 0.64$], $\beta = -.32$, $p = .055$); this did not change when controls were added. This is further supported by results on stress, which showed that while the coast VR group reported significantly lower stress scores than standard care ($B = -.81$ [$SE = 0.35$], $\beta = -.31$, $p = .025$), the urban VR group did not ($B = -.45$ [$SE = 0.34$], $\beta = -.18$, $p = .189$); this did not change when controls were added. Table 5 presents the means and standard deviations for the key variables in Study 2.

Vividness of memories and intrusive thoughts. As with Study 1, however, there was no indication that memory vividness or intrusive thoughts accounted for any effect on recollected pain. Specifically, reports of vividness at follow-up were not significantly different, compared with standard care, for either the coast VR ($B = -.74$ [$SE = 0.60$], $\beta = -.19$, $p = .220$) or urban VR ($B = -.28$ [$SE = 0.59$], $\beta = -.06$, $p = .675$). Findings for intrusive thoughts were similarly nonsignificant: coast VR ($B = .39$ [$SE = 0.80$], $\beta = .08$, $p = .625$); urban VR ($B = -.26$ [$SE = 0.79$], $\beta = -.05$, $p = .740$).

Attractiveness, perceived restoration, and presence of the VR content. The coast VR was rated as more attractive ($M = 4.03$, $SD = 0.78$) than the urban VR

($M = 3.15$, $SD = 0.71$), $F(1, 37) = 13.37$, $p = .001$; and also as more restorative (coast $M = 3.40$, $SD = 0.75$; urban $M = 2.86$, $SD = 0.61$), $F(1, 37) = 6.18$, $p = .018$; but the two did not differ in rated sense of presence in the environment (coast $M = 5.31$, $SD = 2.04$; urban $M = 4.60$, $SD = 2.42$), $F < 1$.

Discussion

Supporting our central hypotheses, and replicating and extending the results of Study 1, Study 2 showed that the beneficial effects of VR held for a sample of real dental patients who experienced treatments such as extractions and fillings. Most importantly, the findings only held for our natural, coastal, VR, and were not replicated by our newly included urban VR. If the effect were solely due to distraction, the content of the VR should not matter (as long as the user has a similar array of stimuli and size of VR, and interacts with it in the same way—which was the case here). Replicating Study 1, however, we again found no support for the processes proposed by EI theory to account for why recalled pain might be lower in the coast VR condition. We recognize, however, that our sample size calculation was based on this variable and as, due to reasons beyond our control, the desired sample size was not achieved, there may be insufficient power to demonstrate significant differences in this variable in the current study.

General Discussion

Although the literature on nature benefits in general is flourishing, much less research has focused on exploring these benefits in the context of health care. Two studies, an experimental laboratory study and a randomized controlled trial, showed that a virtual coastal environment reduced experienced pain reported immediately after an aversive experience, and recalled pain 1 week after the experience. The findings replicated across both a student sample asked to hold a hand in cold water and a sample of dental patients undergoing treatment. This consistency is found even though the dental patients in Study 2 received standard pain control in the form of local anesthetics; no such pain control was available to the participants in Study 1. While some previous research has shown that VR distraction can lower pain (Guo et al., 2015; Sil et al., 2014), the *content* of the VR has been neglected. Especially in Study 2, we showed that the pain reduction was only found for a restorative coastal environment but not for a built urban environment, even though we included natural elements in the city to provide a conservative test. The latter finding speaks against a mere distraction effect, because if it were distraction both VR environments should have had similar effects. It thus appears that

particular VR environments could provide greater benefits for patients' pain experiences. Future research should focus on unraveling the exact mechanisms that can explain these effects by systematically varying the (natural) content of the VR environments.

Previous work has studied the influence of the environmental context on patient health and well-being in general (Dijkstra, Pieterse, & Pruyn, 2006; Joseph, Choi, & Quan, 2015), and on pain in particular (Malenbaum, Keefe, Williams, Ulrich, & Somers, 2008). Both nature and VR have been identified as promising approaches to improve the experience of patients undergoing medical treatment but had not previously been combined in a systematic fashion. Our findings are in line with literature, showing that contact with nature, even indirect contact through windows (Ulrich, 1984), can influence physical and mental well-being (Hartig et al., 2014). More importantly they address a key restriction of using nature in health care, namely that access is restricted, especially in potentially painful or anxiety-inducing health care contexts. Using VR technology has several advantages over other ways in which nature had previously been introduced into health care settings: (a) It has fewer hygiene-related issues than real plants; (b) it can be used even when lying back and undergoing specific treatments; (c) the patient has control over the experience, navigating through a virtual environment, in a context typically characterized by low control; and (d) it excludes potentially aversive visual cues. Our research suggests that VR technology has patient benefits in situations where real exposure to nature is unfeasible. Specifically, it supports the notion that nature can be applied to manage acute pain in patients, and VR provides an opportunity to do so in the absence of real views or experiences.

With the growing use of VR as a distraction intervention in health care settings, it is important to address the question, to what extent VR interventions are more or less successful in helping patients cope with procedural pain than other types of distraction interventions. In general, effects of VR distraction on pain, compared with control conditions, are large (see for a review, Kenney & Milling, 2016). There are a few studies in which other distraction interventions were used and compared with VR distraction. For example, Kipping and colleagues (2012) demonstrated that VR distraction resulted in less pain medication use, compared with standard distraction such as watching television, music, or stories. However, results on all other pain measures were nonsignificant. To get a full understanding of the potential analgesic effects of VR compared with other distraction techniques or pharmacological pain management, direct comparisons are needed in future studies, and a systematic assessment of existing studies should be undertaken.

In a novel application of a cognitive psychology approach, we explored the role of vividness and intrusive thoughts to learn about the memory process during painful experiences. However, we found no evidence that VR reduced the vividness and intrusiveness of memories as argued by the EI theory (Kavanagh et al., 2005). For Study 1, this could be explained by the highly artificial nature of the overall experience. While using an experimental paradigm to induce pain is very suitable for the purpose of scientific research, this specific paradigm may not have strong enough effects on participants' daily life to trigger intrusive memories. However, Study 2 did not support our hypothesis either. It could be argued that this is due to relatively low pain during dental treatment as dentists use local anesthetics to control pain. In contrast, VR distraction is often used for burn-injured patients for whom pharmacologic analgesics need to be complemented by nonpharmacologic techniques due to the high levels of pain they experience (Sharar et al., 2014). Testing EI theory in the context of burn treatment could be worth pursuing as treatment for burn-injured patients has a strong repeating character and influencing memories of the treatment could provide benefits for those patients. Nevertheless, in the current dental context we were able to influence the recollections of pain, which is important, given that expectations of future experiences are heavily influenced by recollections (however inaccurate) of the original experiences (Kent, 1985). A recent study demonstrated this key role of recollections of experiences, showing that recollections of past dental appointments influence behavioral intentions to attend future appointments (Schneider, Andrade, Tanja-Dijkstra, White, & Moles, 2016).

Taken together, our research supports the previous positive findings of VR distraction in acute pain management, and suggests that VR nature can be used in combination with traditional analgesics. Previous research demonstrated that the quality of the VR equipment is of importance in the effectiveness of the pain reduction properties of the technique (Hoffman et al., 2006). Our results demonstrate that the *content* of the VR is pivotal: A virtual walk along a coastline was most beneficial in reducing experienced and recollected pain. With the fast growing technological possibilities, this research points to the need to carefully consider VR content and existing theories of nature and well-being when applying VR distraction in clinical pain management.

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